

# Structural Testing of Geopolymer Pipe & Culvert Mortar Lining System

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## Overview of Trenchless Technology - Terminology and Methods:

- Non-Structural Sprayed Linings
- Robotic Repair
- FRP (Fiber Reinforced Plastic)
- Slip-Lining (Various Types)
- Spiral Wound
- CIPP (Cured in Place Pipe)
- **Centrifugally Cast Geopolymer**
  - **Case Study on CMP Culvert**

## Testing of Centrifugally Cast Geopolymer Systems:

- Initial Cement Culvert Testing
- Queen's University CMP Burial
- Advanced Testing with La Tech University

## Conclusions and Recommendations



# Overview of Trenchless Technology

Applications for Culvert Repair, Rehabilitation and Renewal

## Definitions

- **Trenchless Technologies**

A family of methods, materials, and equipment capable of being used for the installation of new or replacement or rehabilitation of existing underground infrastructure with minimal disruption to surface traffic, business, and other activities (NASTT).

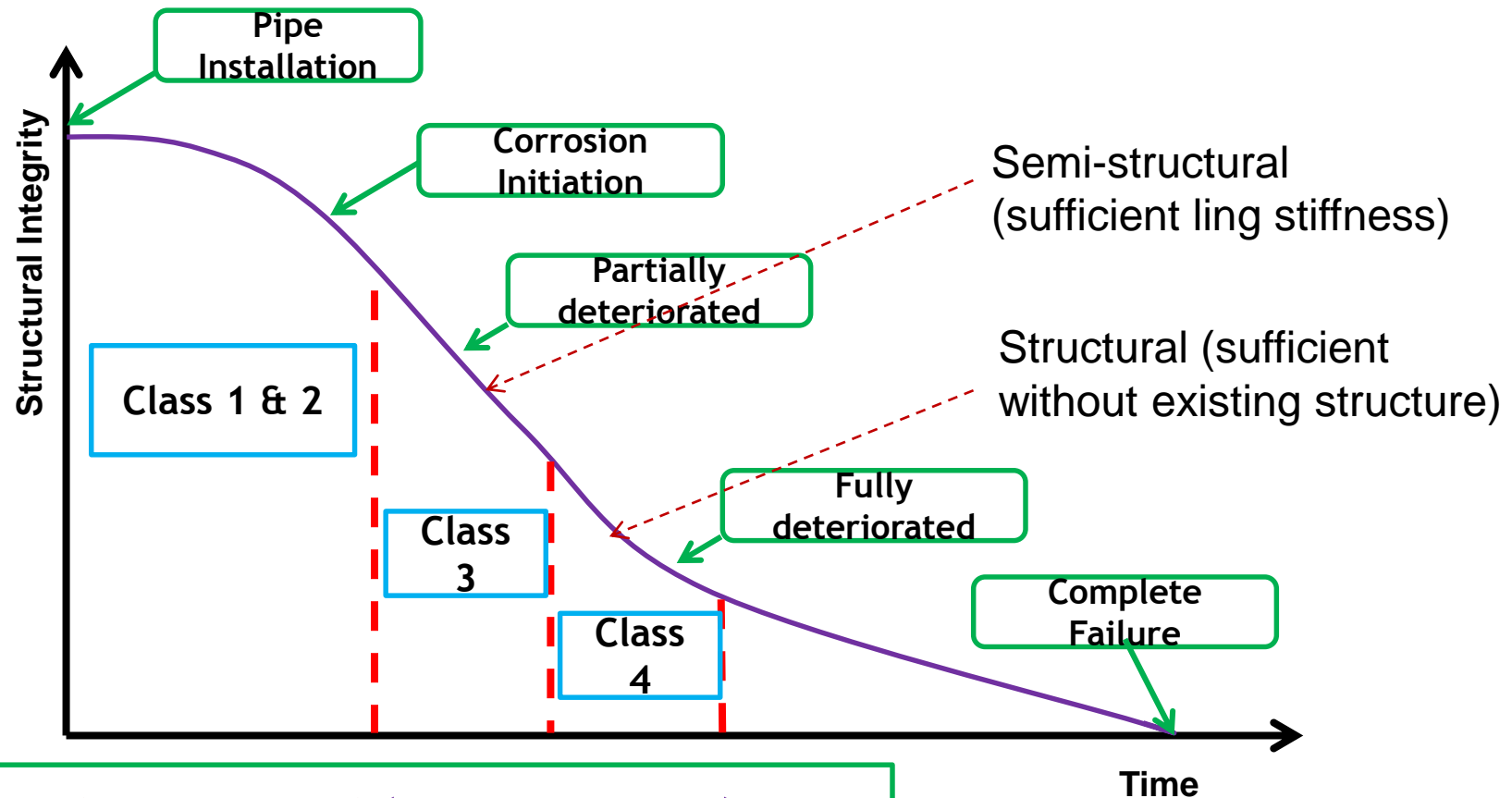
- **Rehabilitation**

All measures for restoring or upgrading the performance of an existing pipeline system (EN / ISO).

### Definitions

- **Partially Deteriorated Pipe (ASTM F1216 - CIPP Standard)**
  - The original pipe can **support the soil and surcharge loads** throughout the design life of the rehabilitated pipe.
  - the soil adjacent to the existing pipe must provide adequate side support.
  - The pipe may have longitudinal cracks and up to 10 % distortion of the diameter.
- **Fully Deteriorated Pipe (ASTM F1216 - CIPP Standard)**
  - The original pipe is **not structurally sound and cannot support soil and live loads** or is expected to reach this condition over the design life of the rehabilitated pipe.
  - This condition is evident when sections of the original pipe are missing, the pipe has lost its original shape or the pipe has corroded due to the effects of the fluid, atmosphere, soil, or applied loads.

### Structural Condition Progress



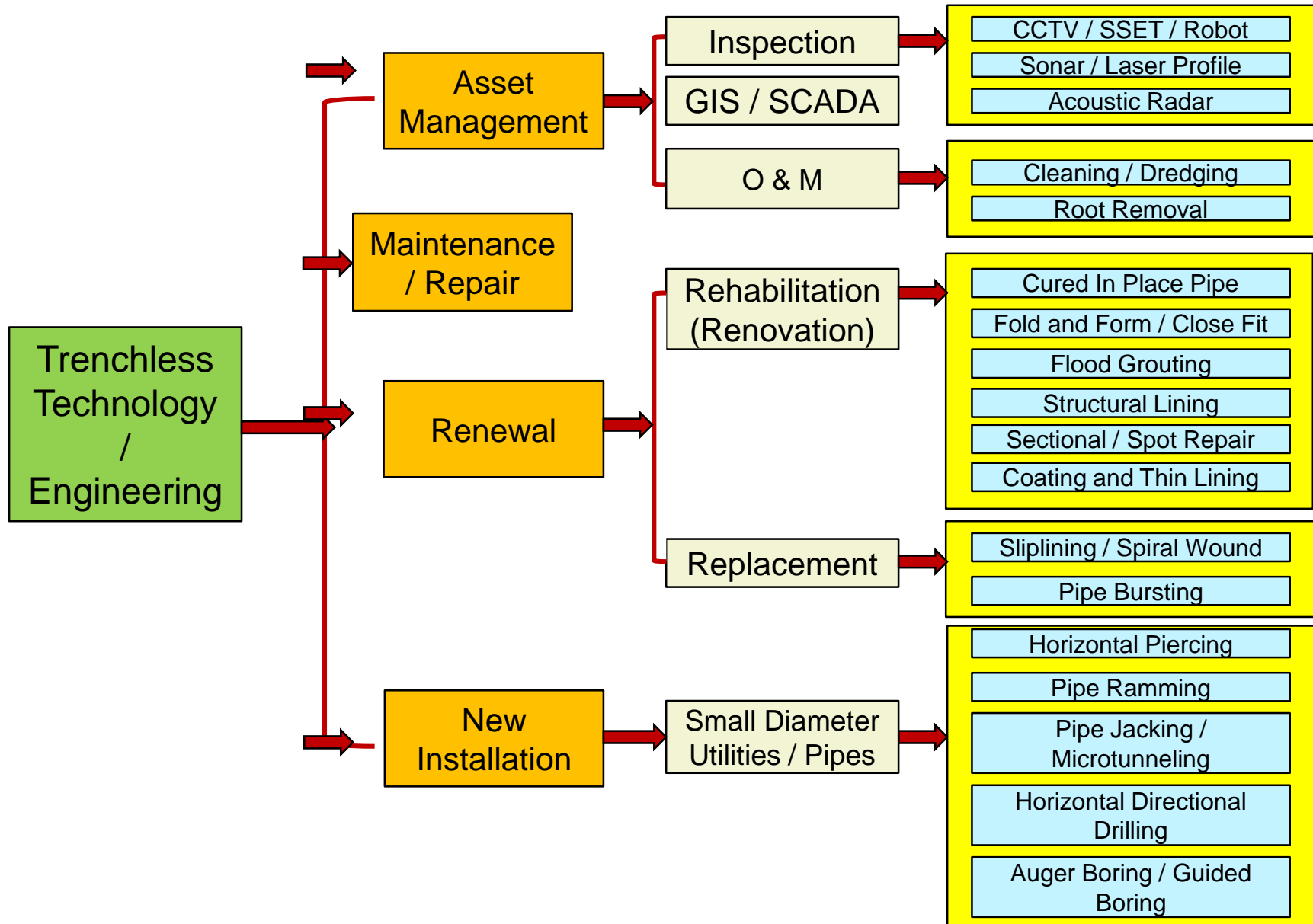
- Polymer Lining
- Cement Lining

- Geopolymer Lining
- Sliplining
- Spiral Wound Lining
- CIPP

- Auger Boring
- Pipe Bursting
- HDD
- Microtunneling, etc

# Trenchless Technologies

## Classification Tree



## Decision Factors

**Many factors affecting a decision of technology selection.**

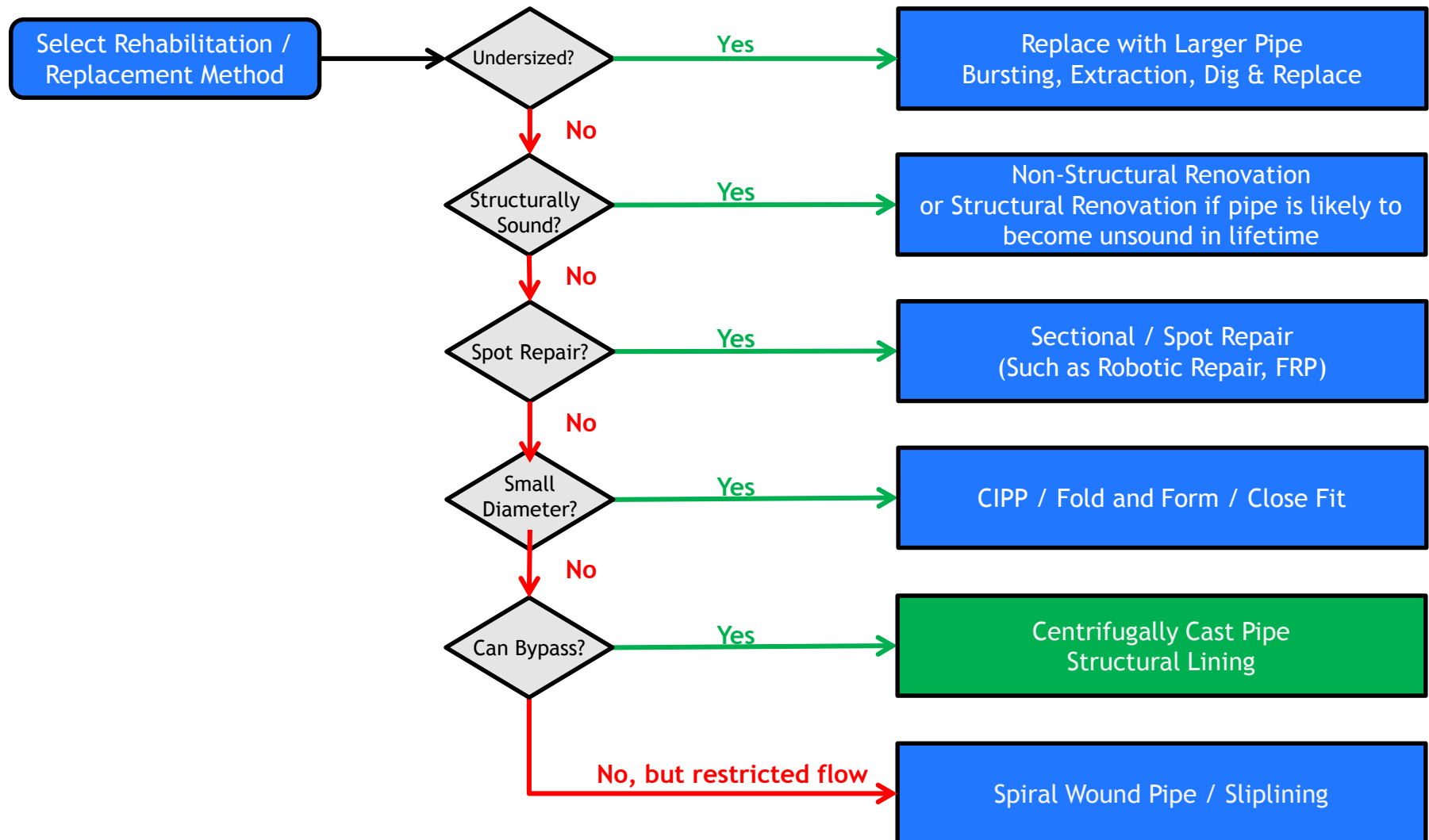
- Capital (Budget)
- Man entry Requirement or Permissible.
- Existing Culvert / Pipe Size / Length
- Maximum Allowable Size Reduction
- Structural Condition / Assessment
- Hydraulic Condition / Assessment
- Job Schedule
- Groundwater Table
- Soil and Rock Properties
- Dead Loads and Live Loads
- Infiltration / Inflow / Exfiltration
- Flow Condition / By-pass Requirement
- Soil and Rock Properties
- Dead Loads and Live Loads
- Infiltration / Inflow / Exfiltration
- Flow Condition / By-pass Requirement



# Trenchless Technologies

## Simplified Method Selection

Choosing a method of renovation involves understanding the current status, size, type, intended service conditions and life expectancy of the pipe to be repaired.



**Non-structural pipe renovation** are method that rely on the host pipe to meet integrity requirements. Main purpose of non-structural lining is to stop corrosion.

**Cement mortars** are highly alkaline and protect the host pipe against metallic corrosion. The relatively smooth internal surface of the liner reduces hydraulic roughness, improving the flow characteristics of the host pipe. The liner, when bonded with the wall of the host pipe, provides excellent protection against corrosion.

**Epoxy, polyurethane, and polyurea spray-on liners**, like cement mortar, protects the host pipe against corrosion and improves the flow characteristics of the host pipe.

Both liners are typically thinner than cement mortar liners. However, these liners are more expensive and require careful quality control during application and curing to ensure that the lining is free of defects that would allow corrosion to restart.

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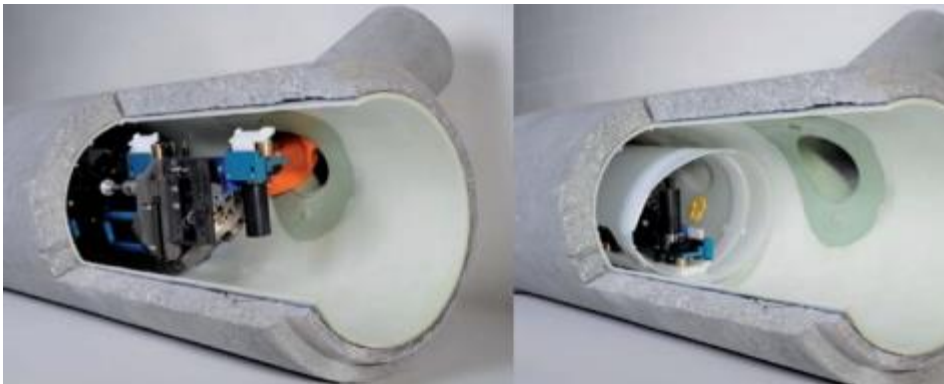
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# Repair

## Robotic Repair

- Robotic repair is mainly used to eliminate cracks in pipe. the robot grinds and then filled the area with polymers such as epoxy mortar.
- Suitable for small diameter pipes.
- Can be used any shape of pipes.
- Tools and robots are expensive.



# Repair

## Sectional Repair using FRP



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**Fiber Reinforced Plastic (FRP)** is the industrial term used to describe the use of carbon or other high strength fiber combined with an epoxy matrix to reinforce an existing structure. While this technique is classified as a structural repair and can be used to increase the structural integrity of the host pipe, it does rely on the host pipe to provide some of the structural requirement.

Carbon fiber strips are applied by hand or with machines almost like wallpaper with an epoxy matrix that is specially formulated to bond to the host pipe and create a composite structure. This technique is primarily advantageous for spot repairs due to the material cost.



*Carbon Fiber Wrap of Concrete Pipe*

*Photo - North Dakota DOT*

### Advantages

- Good for small section repair
- Minimal thickness
- Only small effects on hydraulics
- Can be used on any shape of pipe
- Can be used around large curves

### Disadvantages

- Pipes must be larger than 900 mm at present.
- Requires by-pass
- Higher cost than other typical solutions for large sections
- Required dry pipe



# Slip Lining

## Conventional



Annular Space



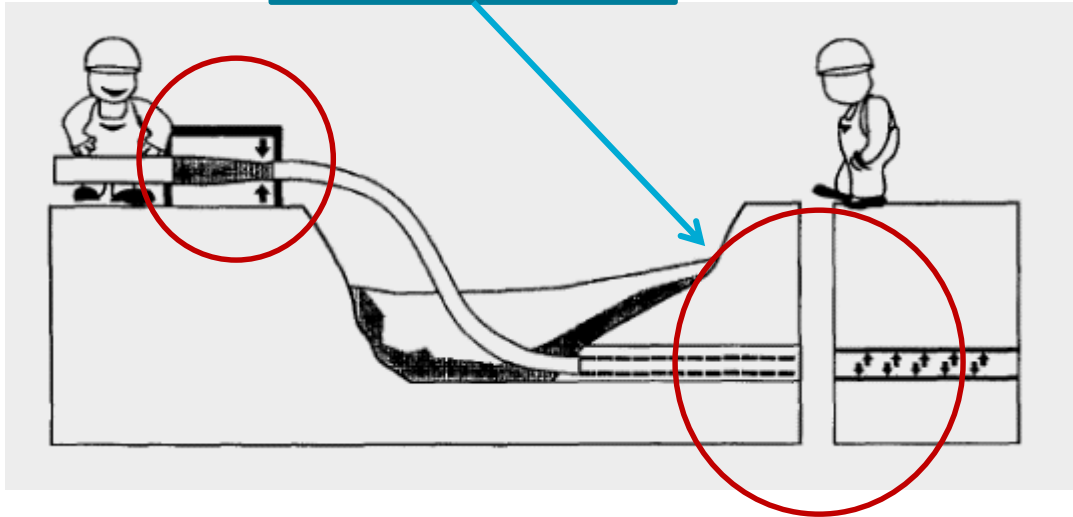
Lining with a continuous pipe for which the cross section is reduced to facilitate installation and reverted after installation to provide a close fit to the existing pipe. Use flexible pipe materials such as PE or PVC.

- Sectional (Discrete) Pipes
- Continuous Pipes

# Modified Slip Lining

## Close Fit

Close Fit



Lining with a continuous pipe for which the cross section is reduced to facilitate installation and reverted after installation to provide a close fit to the existing pipe



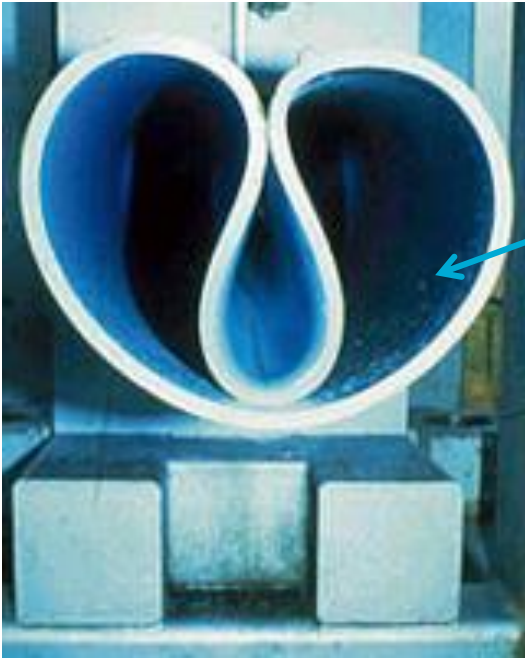


# Modified Slip Lining

## Fold and Form

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Fold

Temp.  
Bending

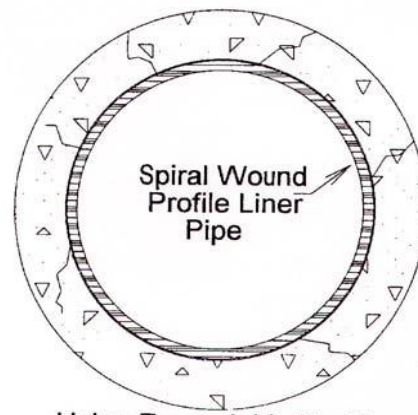
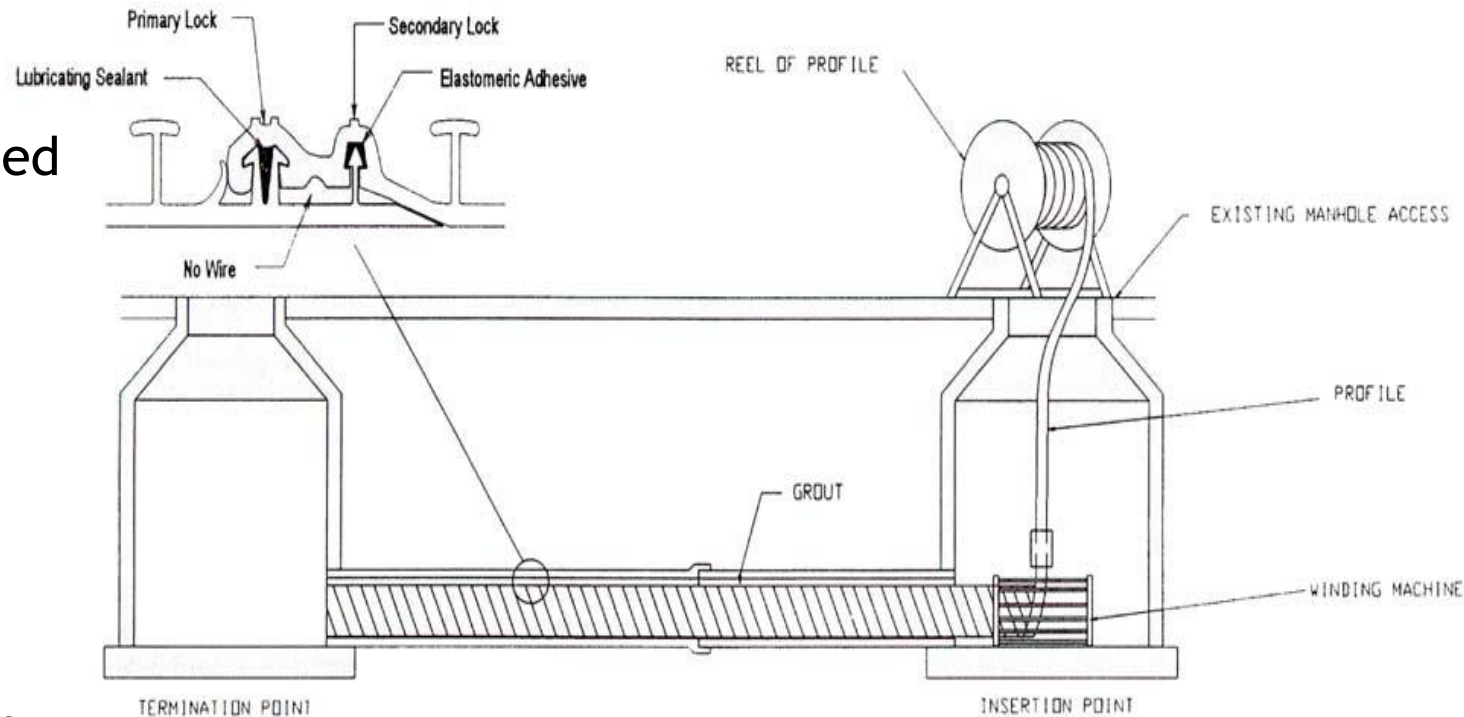


FORM  
reverted after installation  
to provide a close fit to  
the existing pipe

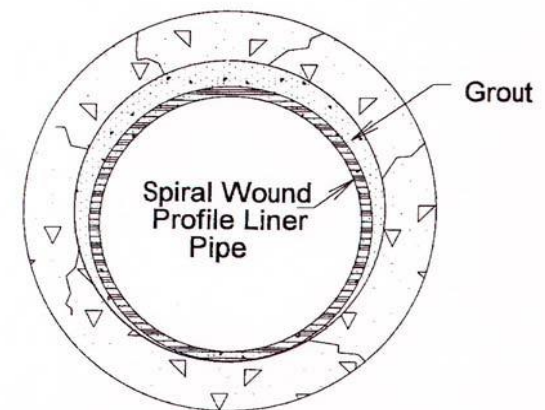


# Spiral Wound Lining

- Ribloc developed in Australia in 1980
- Originally formwork for cast in place pipe
- Mostly used for medium to large size sewer
- Low pressure rating



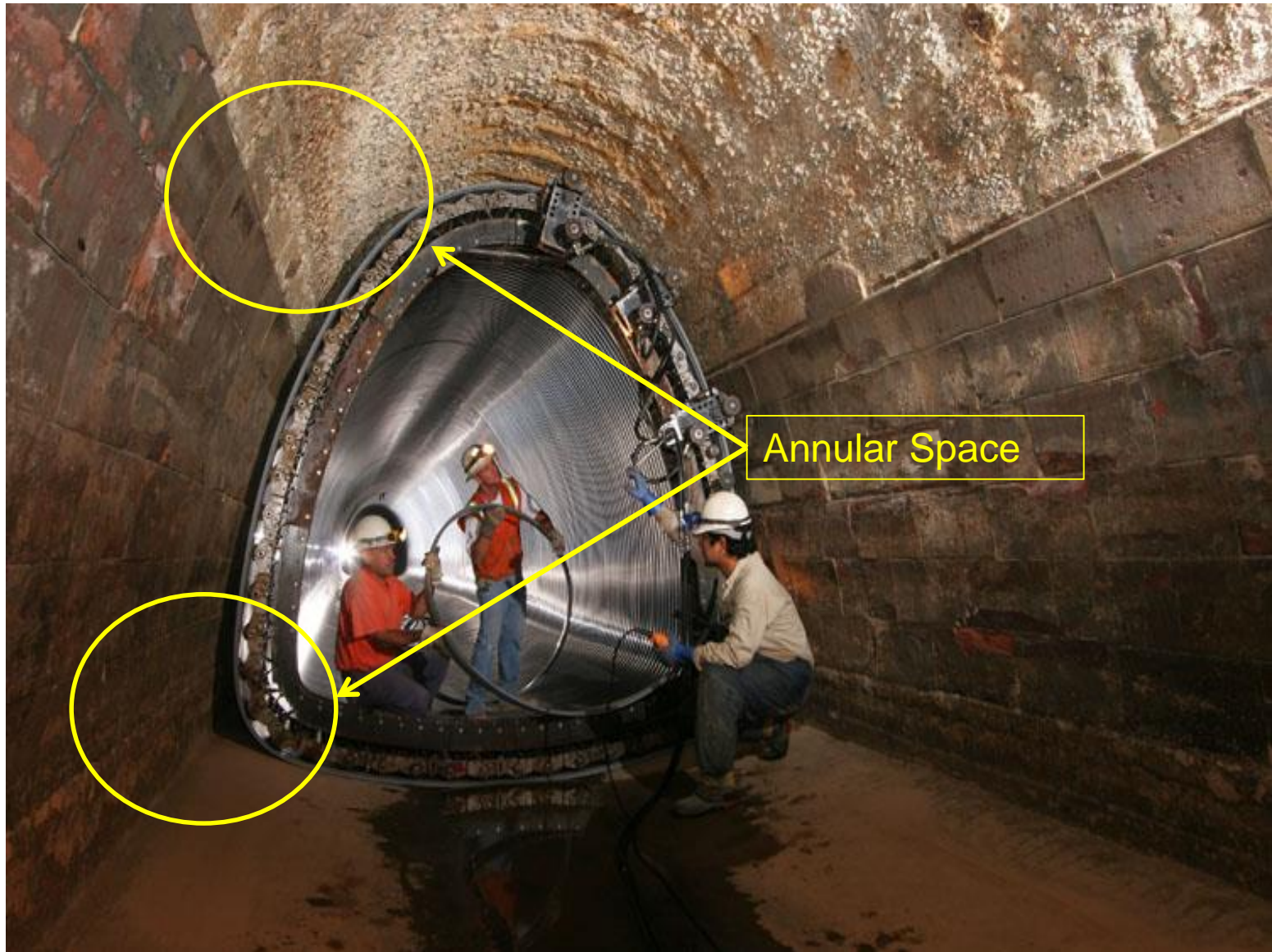
Using Expandable Profile Liner Pipe Pressed Against Existing Pipe Wall



Using Fixed Diameter Profile Annular Space Filled With Grout



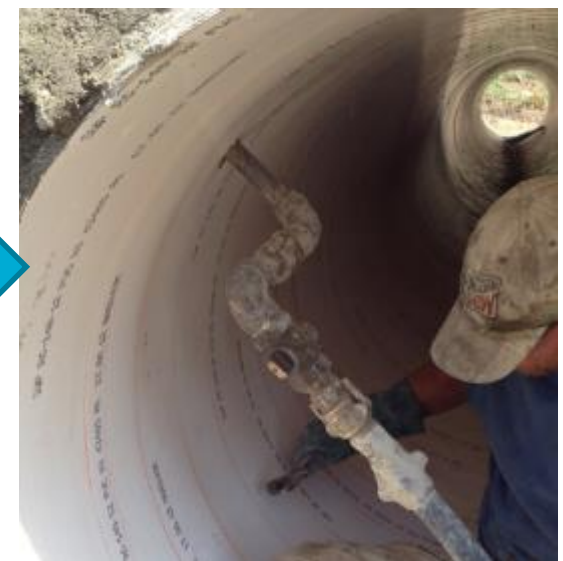
# Spiral Wound Lining



# Spiral Wound Lining

## Example

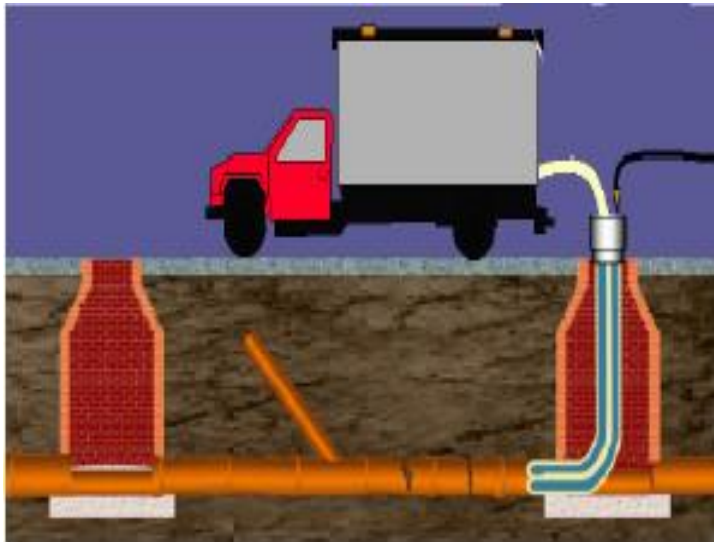
SWL for medium and large diameter circular / non-circular roadway culverts rehabilitation.



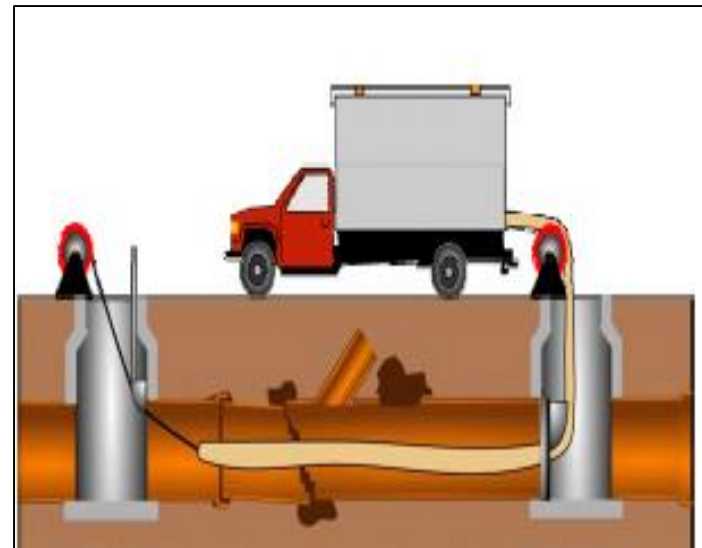


## CIPP

- Most popular trenchless lining technology
- Invented in 1971 in the U.K. (Eric Wood)
- Lining with flexible tube impregnated with thermosetting resin
- Can be used for both partially and fully deteriorated condition
- Gap spanning

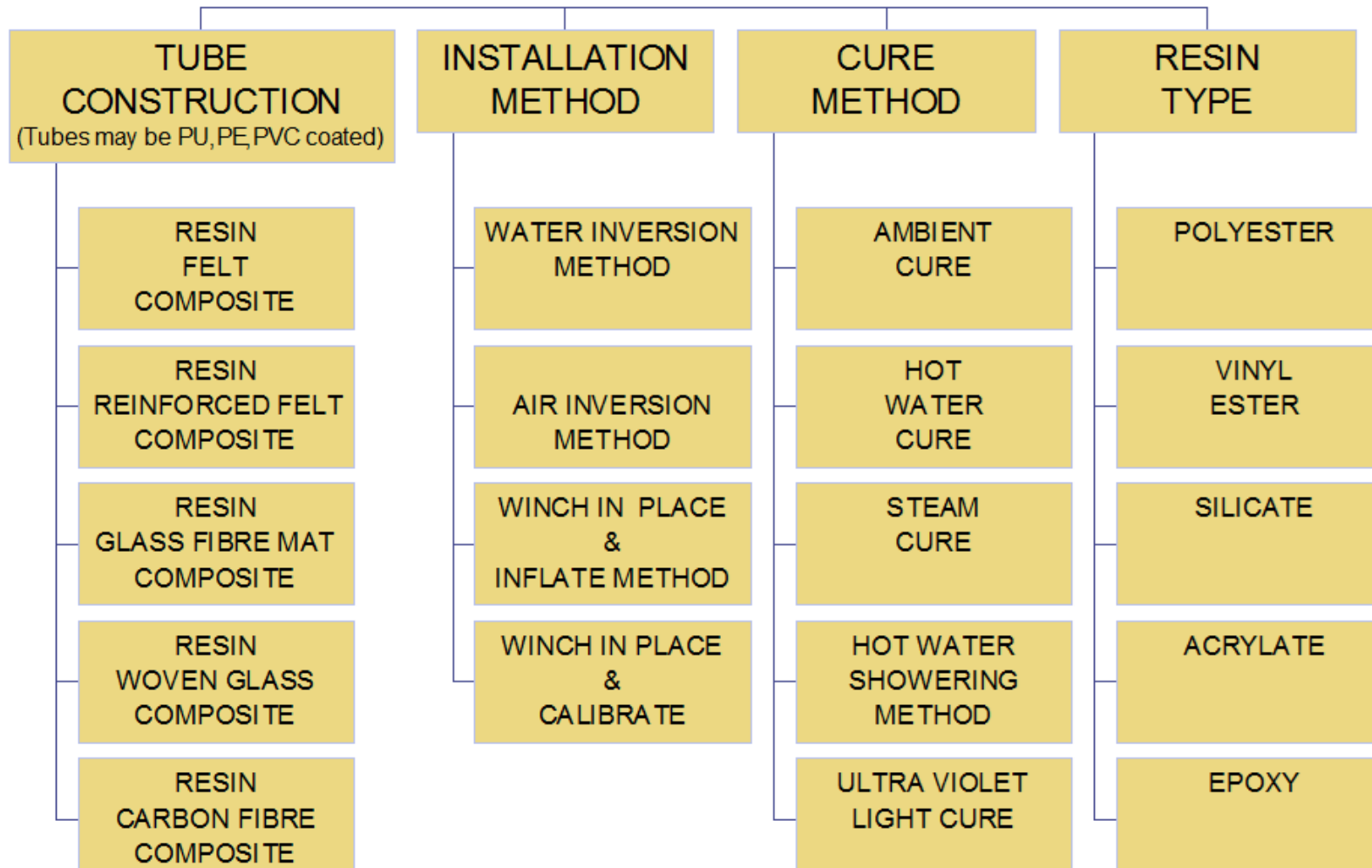


**Inversion Process**



**Winch-Pulling Process**

# CIPP Technology Variants



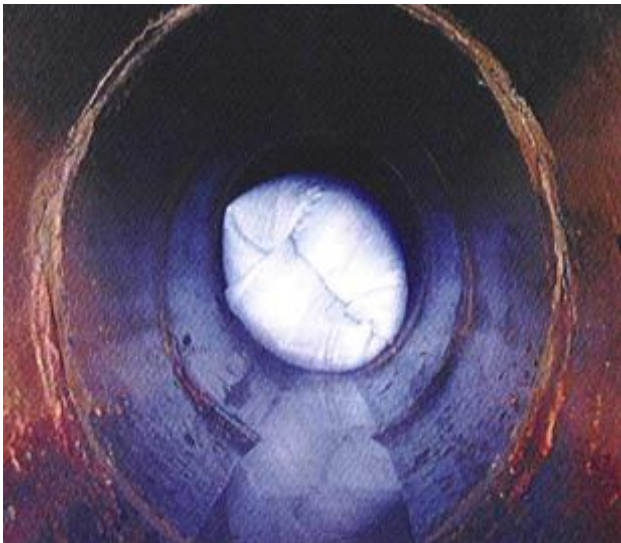
# Trenchless Technologies

## Cured-In-Place-Pipe (CIPP)

- May be installed to reduce infiltration/exfiltration
- May be installed to resist external load
- May be installed as a bonded lining for corrosion protection
- May be a **semi-structural** lining for hole and gap spanning
- May be a **fully structural** lining designed to support structural loads and restore fabric
- Performance will depend on bonding, thickness, and reinforcement



## CIPP Installation Process



<http://www.sakconst.com/cipp-projects.htm>



# Trenchless Technologies

## Cured-In-Place-Pipe (CIPP)

## Curing Processes



UV curing →



### Advantages

- Suitable for Round Pipes
- Cost effective solution for pipes less than 1.5 m
- Consistent in plant manufactured product
- Choice of resins to suit application
- Can negotiate offsets, transitions and multiple 90 degree bends (creating wrinkles)

### Disadvantages

- Requires by-pass
- Higher cost and non-plant wet out for diameters above 1.5 m
- Larger diameters require excavation or entry pits.
- Styrene based chemistries
- Laterals require cutting the liner and introducing possible failure points
- Large on-site footprint
- Infiltration can move behind liner.
- Larger diameters become difficult to complete.
- Pipes must be round (or close to round)

**Structural Renovation** methods do not require the structured-wall of the host pipe to contribute to the ring stiffness needed to satisfy the integrity requirements of the finished renovation.

**Centrifugally Cast Pipe** employs a similar spin casting process as a non-structural mortar lining, but cementitious materials is applied to a thickness that creates structural integrity of a whole new pipe within the host structure. Typical wall thickness of structural cementitious mortars range from 1½ inches to 4 inches depending on the specific design requirements and service application of the pipe.



*GeoSpray™ Centrifugally Casting  
in Action*



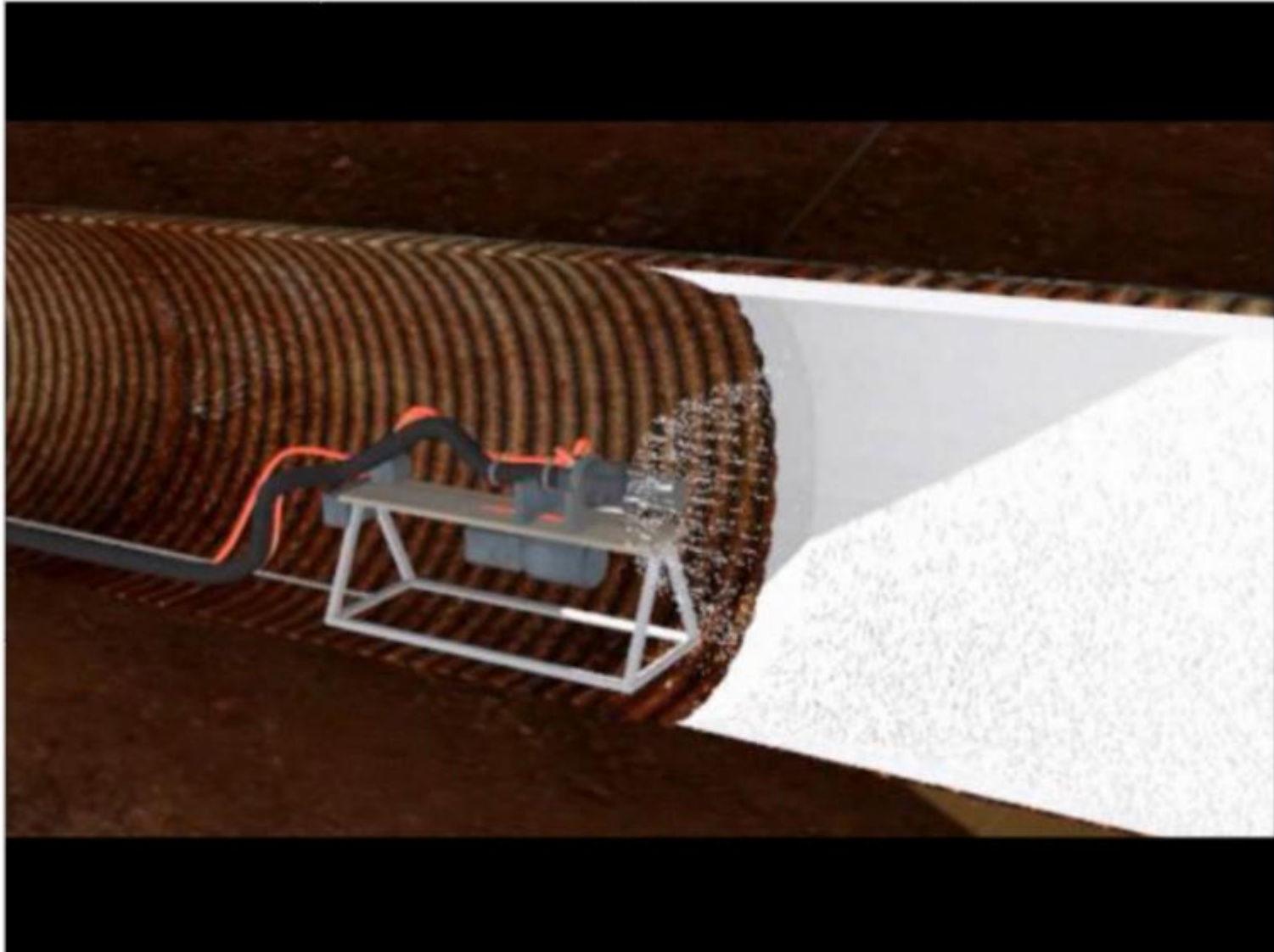
*Close-Up View of GeoSpray™ Liner*

# Spray on Application Video

## Typical Application Process

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### Advantages

- Low Cost
- Minimal thickness
- Only small effects on hydraulics
- Can be used on any shape of pipe
- Can be used around large curves
- Laterals are “feathered in”
- Moist pipe conditions are preferred
- Geopolymers don’t form cold joints
- By-Pass can be reduced in just a few hours.

### Disadvantages

- Pipes must be larger than 900 mm at present.
- Requires by-pass





A topographic map of a hilly area with contour lines. A road runs diagonally across the map. A dashed line indicates a culvert installation crossing the road. Several small blue squares are placed along the road, likely representing other infrastructure or survey points.

# Rock Springs, Wyoming

Arched Culvert Case Study

Installation Completed  
May 2014

# GeoSpray Case Study

## Rock Springs, Wyoming - USA

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### Project Details:

- Rock Springs, Wyoming
- Arched Storm Culvert
- 700 Linear Feet of CMP
- 48 Inch High
- 72 Inch Wide
- 126,000 lbs of GeoSpray Applied
- Contractor - IPR South Central



# GeoSpray Case Study

## Rock Springs, Wyoming - USA

The initial culvert was in very poor shape with most of the invert corroded and lost with soil voids as deep as 2 ft below the pipe



Significant damage also existed in the crown with some sections caved in.





# GeoSpray Case Study

## Rock Springs, Wyoming - USA

Prior to repair the pipes required bracing for safe operation.



The finished culvert created a new structural system, integrated with the junction boxes



# GeoSpray Case Study

## Rock Springs, Wyoming - USA



**The project was completed in under 1 week with no disruption to traffic along the roadway**

The background of the slide is a light blue topographic map. It features several blue lines representing roads or paths, some of which are highlighted with thicker lines. There are also blue rectangular shapes that look like building footprints or industrial sites. The map is overlaid with a grid of thin blue lines.

# Testing of Centrifugally Cast Geopolymer Linings

Applications for Culvert Repair, Rehabilitation and Renewal

# Sirim QAS International Testing

Geopolymer liner applied to RCP

Testing Completed December 2013

- 4 new RCP pipes 1.7 m (~67 inch) outer diameter, 1.5 m (~59 inch) inner diameter with a wall thickness of 200 mm (~8 inch) and 1 m in length (~ 39 inch) were coated with GeoSpray geopolymer mortar under the following conditions:
  - » Sample 1 - Control Pipe - No Coating
  - » Sample 2 - 50 mm (~2 inch) nominal coating
  - » Sample 3 - 38 mm (~1.5 inch) nominal coating
  - » Sample 4 - 38 mm (~1.5 inch) nominal coating with additional reinforced wire mesh
- Test were conducted under the following Malaysian standard
  - » MS 881: Specification for Precast Concrete Pipes and Fittings for Drainage and Sewerage.
  - » Part 3: Specification for pipes and fittings with Ogee Pipes
  - » Appendix F: Crushing strength test for pipes.





## 4 New RCP Test Pipe Samples\*

Outer Diameter = 1.7 M (~67 inch)

Wall Thickness = 200 mm (~8 inch)

Inner Diameter = 1.5 M (~59 inch)

Length = 1M (~39 inch)

\*Coated with GeoSpray geopolymer

General Testing Apparatus and Configuration

# Sirim QAS International Testing

## Test Results



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NO	TEST RESULT				REMARK
	Test Sample	Weight (kg)	Proof Load (kN) First Crack Observed	Ultimate Load (kN)	
1.	C1 - Untreated Precast Concrete Pipe	1875	45	53	The width of 0.5 mm crack is identified at the bottom side
2.	C2 - Precast Concrete Pipe Treated with 50 mm thickness of GeoSpray	2842	100	195	The width of 0.26 mm crack is identified at the bottom side
3.	C3 - Precast Concrete Pipe Treated with 38 mm thickness of GeoSpray	2663	89	164	The width of 0.06 mm crack is identified at the top and bottom sides
4.	C4 - Precast Concrete Pipe Treated with 38 mm thickness of GeoSpray and Reinforced with wire mesh	2565	56	200	The width of 0.02 mm crack is identified at the top and bottom sides

**Sample 1** Control Pipe - No Coating

**Sample 2** 50 mm (~2 inch) nominal coating

First Crack +122%; UL +268%

**Sample 3** 38 mm (~1.5 inch) nominal coating

First Crack +98%; UL +209%

**Sample 4** 38 mm (~1.5 inch) nominal coating with additional reinforced wire mesh

First Crack +24%; UL +277%

Source - Sirim QAS International Test Report No: 2013-CB4822

- A 38 mm (~1.5 inch) thick unreinforced GeoSpray geopolymer liner increased the initial crack resistance of the original RCP pipe by nearly 100% and increased the ultimate load capacity of the **original pipe by over 200%**. Ultimate load capacity of 164kN (~37,000 lbs-force)
- A 50 mm (~2 inch) thick unreinforced GeoSpray geopolymer liner increased the initial crack resistance of the original RCP pipe by over 120% and increased the **ultimate load capacity of the original pipe by over 250%**. Ultimate load capacity of 195 kN (~44,000 lbs-force)
- A 38 mm (~1.5 inch) thick wire reinforced GeoSpray geopolymer liner increased the initial crack resistance of the original RCP pipe by approximately 25% while increasing the **ultimate load capacity of the original pipe by over 250%**. Ultimate load capacity of 200 kN (~45,000 lbs-force)





# Queen's University Testing

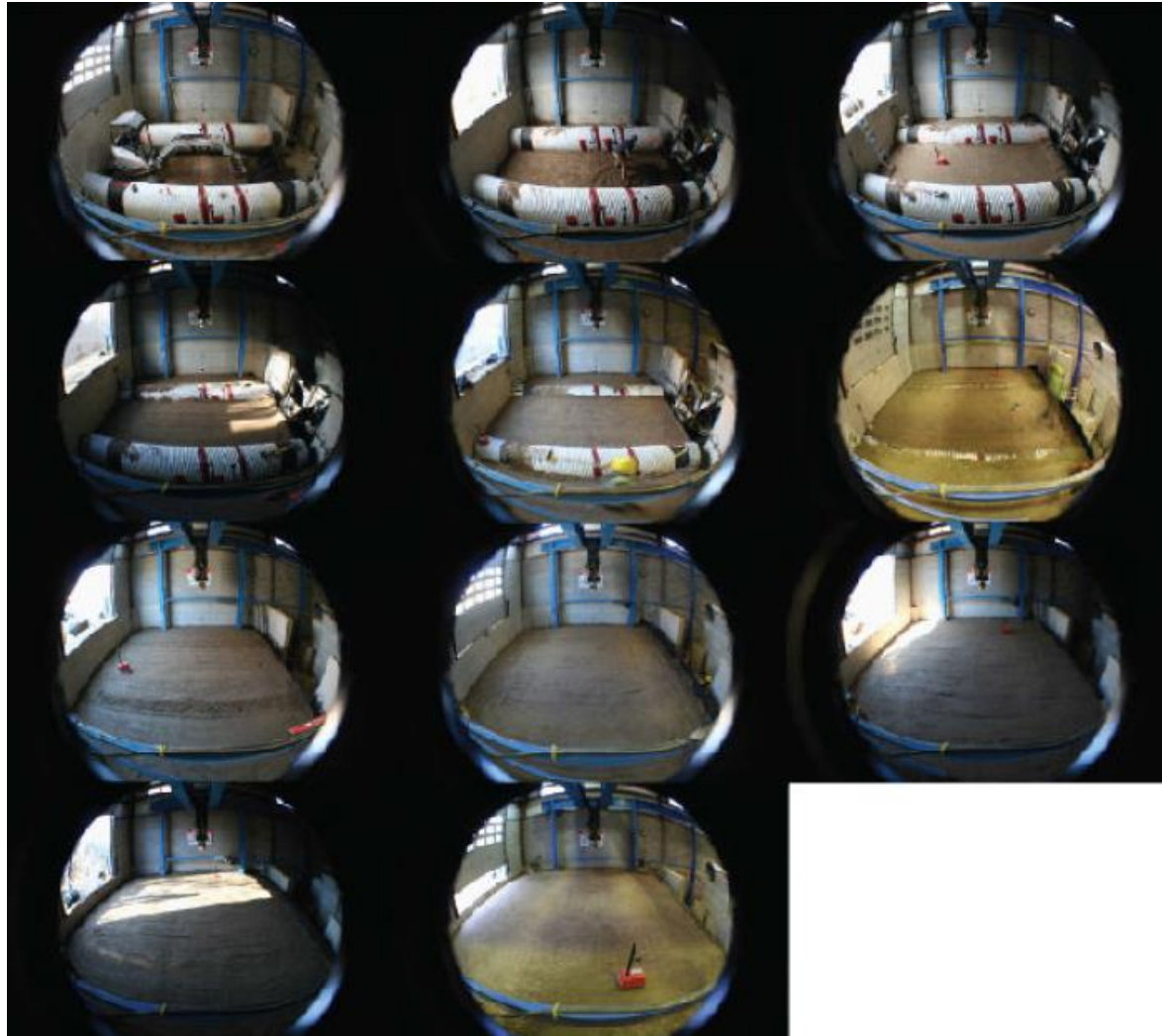
GeoSpray™ geopolymer liner applied to CMP

Testing Completed November, 2013

- 3 damaged and deteriorated CMP culverts were excavated from the E407 Toll Road in Ontario, Canada.
- Two - 1200 mm (~48 inch) in diameter, 7 m (~23 ft) long culverts were assembled and buried in the laboratory under controlled soil fill conditions.
- The assembled culverts were tested under Canadian Highway single axel loads standards under a burial depth of 1200 mm (~48 inches)
- The 2 culverts were then repaired with GeoSpray geopolymer mortar lining with nominal thickness of 50.8 mm (~2 inches) and 76.2 mm (~3 inches).
- The culverts were allowed to cure for 28 days.
- Testing of the culverts was performed under single and double axel loads with buried depths of 1200 and 2100 mm (~48 and 83 inches) respectively.
- Finally, the culverts were loaded to the maximum available load conditions 1200 kN (~270,000 lbs-force).



Assembled and instrumented culverts prior burial and testing



Time lapsed view of culvert burial to 1200 m depth

- The initial samples had significant deterioration in the field.
  - » There were significant perforations along the strips of steel at the levels of the waterlines, with perforations covering from 5% to 60% of those regions.
  - » Up to 30% of the steel thickness was lost from corrosion in the region between the haunches across the invert.
- An initial load was applied to the un-lined buried culverts to test the response of the backfill in the laboratory.
  - » 203 kN - Single Axle Load - 1200 mm fill (~45,600 lbs-force)
- Maximum measured strains of the pipes due to back fill were approximately 10% of the yield strain.
- Measured diameter changes were on the order of 1mm





(a) Beginning of repair



(b) Halfway through first pass



(c) Finishing pass

Series of images showing in laboratory repair of culverts





Image of completed culvert repair - in laboratory

- The GeoSpray geopolymer mortar lined culverts were tested under the calculated service loads:
  - » 203 kN - Single Axle Load - 1200 mm fill (~45,600 lbs-force)
  - » 308 kN - Tandem Axle Load - 2100 mm fill (~69,200 lbs-force)
  - » 325 kN - Tandem Axle Load - 1200 mm fill (~73,000 lbs-force)
- Under these conditions, data as to deflection and culvert response was collected.
- No damage was observed or measured under any of the above conditions for either liner thickness.
- Measured diameter changes under these conditions were on the order of 0.2 mm.

50.8 mm (~2 inch) liner thickness - Calculated Full Service Load 552 kN (~lbs-force):

- » First observed crack observed 650 kN (146,000 lbs-force)
- » Larger cracking observed 750 kN and 800 kN respectively (168,000 and 180,000 lbs-force)
- » Circumferential Crack observed 1150 kN (261,000 lbs-force)
- » Maximum applied load was 1200 kN (270,000 lbs-force)

76.2 mm (~3 inch) liner thickness - Calculated Full Service Load 552 kN (~lbs-force):

- » First observed crack observed 800 kN (180,000 lbs-force)
- » Additional cracking was observed at 850 and 900 kN respectively (191,000 and 202,000 lbs-force)
- » Maximum applied load was 1200 kN (270,000 lbs-force)

- 50.8 mm (~2 inch) liner thickness:

Initial signs of damage to the culvert under load were first observed at 650 kN (146,000 lbs-force) or 18% higher than the fully factored design load of 552 kN (~124,000 lbs-force)

- 76.2 mm (~3 inch) liner thickness:

Initial signs of damage to the culvert under load were first observed at 800 kN (~180,000 lbs-force) or 45% higher than the fully factored design load of 552 kN (~124,000 lbs-force)

- Full reports are now available.



# Further Testing with La Tech Trenchless Technology Testing

GeoSpray™ geopolymer liner applied to CMP, RCP, SonoTube  
Thickness and Ovality Explored

Testing Completed August 2014



Test increasing pipes sizes with liner thickness scaling as the size of the pipes increase.

Types of Pipe: RCP, CMP, Cardboard

Pipe Diameters: 24", 36" & 48" (ID)

Liner Thickness: 24" (0.66" & 1.3")

36" (1", 1.5" & 2")

48" (1.33" & 2.66")

Ovality (CMP): Tested 0,4,6,8,10 & 12%

Preparation: All RCP Pipes were D-Loaded prior to repair with liner.

Full Factorial Experimental Design Performed with Replicates

# Advanced Testing

## Pipe Preparation



# Advanced Testing

## Load Frame





# Advanced Testing

## Testing While Applying Lining

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# Advanced Testing

QC on Materials Conducted by 3<sup>rd</sup> Party

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# Advanced Testing

## Spraying of CMP (Vertical)



# Advanced Testing

## Spraying RCP - Vertical

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# Advanced Testing

## Complete Test Samples

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# Advanced Testing

## Close Up of Sprayed RCP





# Advanced Testing

## Load Frame Ready to Go

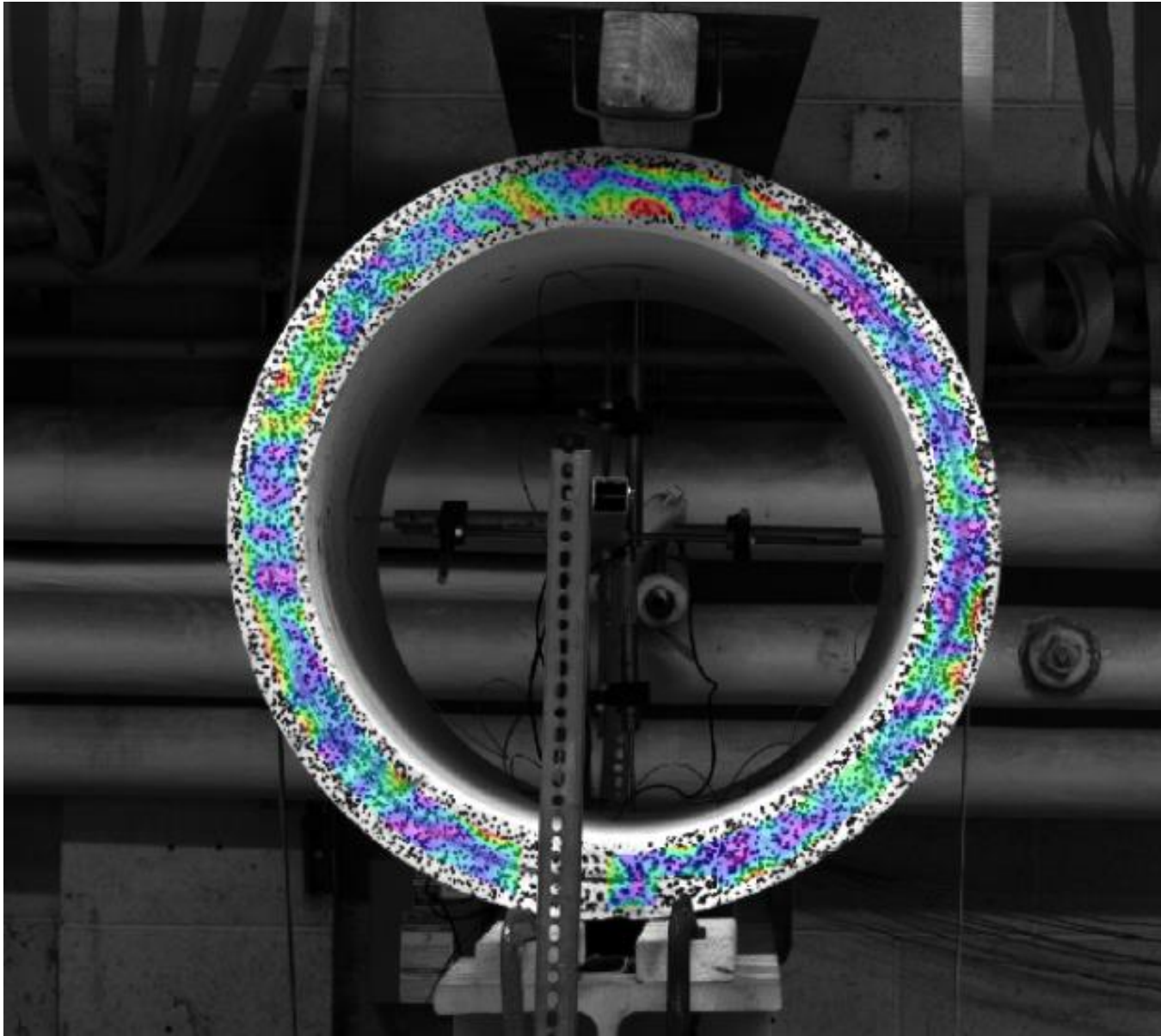
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# Advanced Testing

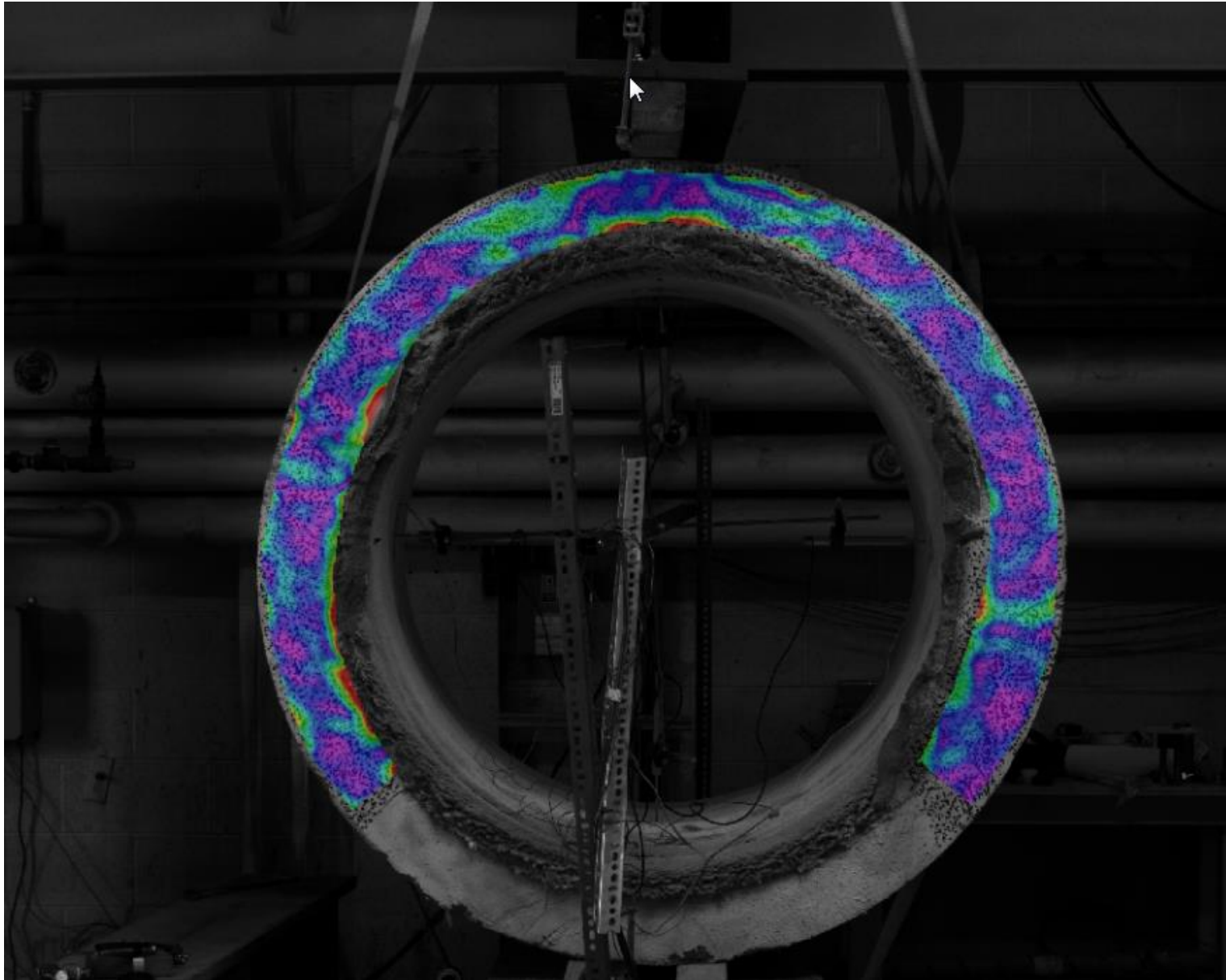
## UnCoated RCP



# Advanced Testing

## Coated RCP Pipe

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# Advanced Testing

## Completed Testing Pipes

### The Land of Destruction





24" RCP	Control 1	Control 2	0.66 " Liner	0.66" Liner	1.33" Liner	1.33" Liner
Load @ Break	17,400	11,800	12,500	10,800	21,700	15,100
% of						
<p>Within experimental error, which all of the RCP pipe that were repaired (independent of liner thickness) were as strong as the original pipe and above the ASTM acceptance standards for new pipe.</p>						
Load @ Break	17,900	20,700	16,100	18,600	28,500	36,000
% of Control	N/A	N/A	-17%	-4%	48%	81%

RCP, CMP and Cardboard Tubes were Tested after 28 days curing.

RCP Pipes tested as good as new pipes with as little as 0.66 inch coating, suggestion that if the reinforcing steel is still good only material thickness of original is needed. If cracking is heavy a thicker lining can be used to restore original strength.

Analysis of CMP pipe is ongoing, but structural performance was observed and little to no effect with oval structures was observed.

The university is conducting further analysis on the results with the intent of publishing peer review models based on the data for assistance in lining design.



# Conclusions

- Trenchless pipe/culvert repair is often a cost effective alternative to traditional dig and replace construction - specifically if a valuable assets exists above the pipe (Road or Structure) or if easements are difficult to obtain.
- Centrifugally Cast Geopolymer Liner are an alternative to CIPP or Slip-lining that require less equipment and a smaller footprint and are generally less expensive solution for pipes larger than 36”.
- Geopolymer liners are structural solutions for various host pipe materials including RCP and CMP.
- Structural testing have confirmed that these materials can be used with confidence.

# Thank You

## Please visit our both in the exhibit hall for additional information

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Construction Engineering & Management Tech.

Purdue Road School - March 2015



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